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Low-Oxygen Atmospheres as a Practical Means of Preserving the Quality of Shelled Peanuts

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Low-Oxygen Atmospheres as a Practical Means of Preserving the Quality of Shelled Peanuts

By Whit O. Slay,[1] Charles E. Holaday,[2] Jack L. Pearson,[3] and Jack A. Pomplin[4]

ABSTRACT

The grade and germinability of 'Florunner' peanuts were generally better maintained for 3, 6, and 12 months in a vacuum at 26 inHg or in an initial vacuum with nitrogen gas backflush to 16 inHg than in conventional ambient or refrigerated atmospheres. The kind of plastic pouch lining (nylon-EVA or nylon-Saran-EVA) of specially designed fiberboard storage boxes had no significant effect on moisture loss. Of all treatments, farmers stock peanuts stored in burlap bags in an ambient atmosphere lost the most moisture and had the largest increase in split, fall-through, and externally damaged kernels. The shipping performance of the boxes and the cost factors of low-oxygen-atmosphere storage are also discussed. Index terms: low-oxygen atmospheres, modified atmospheres, nitrogen, packaging, peanut germination, peanut grade quality, peanut storage, shelled peanuts.

INTRODUCTION

Many of the food products essential to human nutrition must sometimes be stored for extended periods before use. Maintaining quality and protecting them from insects, moisture, or other causes of deterioration during storage is often very difficult and expensive. Chemical methods of preservation and protection cannot always be used, and nonchemical means such as cold storage must be employed. This is often very expensive because of high energy use and the added costs of transportation, labor, or other requirements. Thus, better and less expensive methods for protecting and maintaining the nutritional and quality values of food supplies during storage are needed. One of the more promising methods is the use of low-oxygen atmospheres. Several researchers have reported advantages such as extended quality preservation of foods without need of cold storage, improved sanitation, better insect protection, reduced mold or fungi problems, and preservation of seed germination quality.

Woodruff (1973) cited several advantages of inert gases over air for peanuts stored 12 months at 75° F and 50% to 60% RH in air, nitrogen, and carbon dioxide atmospheres. He found better flavor and sensory scores, less change in some of the chemical components, better oil stability, complete insect mortality, and no effects on germination for up to 3 months of storage. Marzke et al. (1976) stored peanuts in air, nitrogen, and carbon dioxide atmospheres and found that atmosphere had no consistent effect on germination of unshelled peanuts, but shelled stock was nonviable after 6 months. Storage temperature affected quality

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more than did atmosphere. After 12 months of storage, peanuts in nitrogen or carbon dioxide atmospheres had less browning of skin, staleness, or rancidity than those stored in air. These authors further cited work by T.W. Eselgroth[5] that predicted 3 to 6 times longer storage life for some 30 processed foods, including peanut products, when stored in nitrogen or carbon dioxide atmospheres.

Effects of low-oxygen atmospheres on insects have been reported by several researchers. Oxley and Wickenden (1963) found total mortality of grain insects in atmospheres with less than 2% oxygen. Press and Harein (1967) reported similar results but noted insect activity for several months, depending on storage temperatures. Other research has indicated mortality within 12 to 24 hours for certain insects and larvae contained in low-oxygen atmospheres.

Products confined in atmospheres with low concentrations of oxygen are subject to anaerobic enzyme activity. Milner et al. (1947) found that the addition of 1% oxygen to nitrogen was necessary to prevent this type of damage in stored wheat. Marzke et al. (1976) cited numerous reports of anaerobic damage from product or residual mold enzymes in grains and oilseeds stored in atmospheres with less than 1% oxygen. Most of the information indicates that anaerobic damage occurs in products with moderate to high moisture content. Apparently, at low moisture levels, anaerobic activity is severely inhibited in most products.

Other researchers have reported on the effects of low-oxygen atmospheres on aflatoxin growth or production. Wilson and Jay (1975) reported no high levels of aflatoxin growth in high-moisture corn stored in modified atmospheres. Sanders et al. (1968) reported that little aflatoxin was found on inoculated peanuts stored in an atmosphere of 60% carbon dioxide, 20% oxygen, and 20% nitrogen, whereas peanuts in normal atmosphere at 25° C and 90% RH contained 206 μg of aflatoxin per gram of peanuts. Diener and Davis (1977) reported on aflatoxin growth in modified atmospheres and noted that reduction and restriction of growth was most striking when oxygen concentrations dropped from 5% to 1% and then to a trace (0.1%).

Many other researchers have reported results similar to those cited above. Yet, with all this documentation on the advantages and potential benefits to be derived from using low-oxygen atmospheres as a storage medium, their use has been very limited. This is probably because of the relatively high cost of application. In recent years new developments, particularly in materials, make the cost structure appear much more competitive with conventional methods.

A cooperative research project was developed by the National Peanut Research Laboratory, Dawson, Ga., the Container Corporation of America, Carol Stream, Ill., and the Stored-Products Insects Research and Development Laboratory, Savannah, Ga., to investigate the use of low-oxygen atmospheres as a practical means of preserving the quality of peanuts. The objectives were (1) to develop a low-cost package, (2) to test packages and atmospheres for quality-preservation characteristics and insect control, and (3) to make an economic analysis in comparison with conventional methods. The research data were collected from 1976 to 1978.

This report deals with the engineering aspects of the investigation. The other areas of the investigation concerning insects and food-quality parameters will be reported in separate papers by the responsible cooperators.

METHODS AND MATERIALS

'Florunner' (Runner) peanuts obtained directly from the field were artificially dried to a moisture content of 10%. The peanuts were shelled and sized over a reel-type precision grader 16/64-inch slotted screen) to obtain sound mature kernels conforming to official grade standards. These kernels were mixed and divided into two lots, and supplemental drying was applied to establish two moisture levels. Each lot was then divided into 25-lb samples that were placed in specially designed fiberboard boxes with plastic pouch liners. Two types of machines designed for low-oxygen-atmosphere application in this type of package were used to apply various treatments to the samples in determining the effects of three pairs of variables: (1) two peanut moisture contents, 7.6% or 6.9%; (2) two pouch-liner packaging films, nylon-EVA[6] resin or nylon-Saran-EVA resin; and (3) two atmospheres, vacuum at 26 inHg or initial

[5] "How Peanut Products Can Be Improved by Nitrogen Control," Canner 110(11): 16-17,22,24 (1950). "Inert Gas: Safeguard of Quality," Food Eng. 23(12): 72-75, 153-155 (1951).

[6] EVA, ethyl vinyl acetate.

Table 1. — Experimental treatments for shelled-peanut investigation

Treatment No.	Description		
	Packaging material	Atmosphere[1]	Moisture content (%)
1	Nylon-EVA	N_2BF	6.9
2	Nylon-EVA	N_2BF	7.6
3	Nylon-EVA	Vacuum	6.9
4	Nylon-EVA	Vacuum	7.6
5	Nylon-Saran-EVA	N_2BF	6.9
6	Nylon-Saran-EVA	N_2BF	7.6
7	Nylon-Saran-EVA	Vacuum	6.9
8	Nylon-Saran-EVA	Vacuum	7.6
9	Burlap[2]	Refrigerated	7.6
10	Burlap[3]	Ambient	7.6
11	Fiberboard box[4]	Ambient	7.6

[1]N_2BF, nitrogen backflush.

[2]Control, 25-lb samples stored at 37° F and 65% RH.

[3]Control, 25-lb samples.

[4]Control, approximately 1,000 lb of farmers stock peanuts stored in an open-top fiberboard box.

Table 2. — Mean values (%) of grade-quality factors for peanuts at time of storage[1]

Treatment No.	SMK	FTK	SK	BK	EDK	MC[2]
1	98.1	0.5	0.5	0	0	6.9
2	97.5	1.4	.7	0	0	7.7
3	98.1	.5	.5	0	0	6.9
4	97.5	1.4	.7	0	0	7.7
5	98.1	.5	.5	0	0	6.9
6	97.5	1.4	.7	0	0	7.7
7	98.1	.5	.5	0	0	6.9
8	97.5	1.4	.7	0	0	7.7
9	97.5	1.4	.7	0	0	7.7
10	97.5	1.4	.7	0	0	7.7
11	69.6	3.7	2.8	.3	2.4	7.9

[1]See table 1 for treatment descriptions. SMK, sound mature kernels. FTK, fall-through kernels. SK, split kernels. BK, bald kernels. EDK, externally damaged kernels. MC, moisture content.

[2]Values represent all peanut samples within a given treatment.

vacuum (26 inHg) with nitrogen gas backflush to 16 inHg (table 1). Two controls were 25-lb samples of peanuts (7.6% moisture content) in burlap bags stored in refrigerated (37° F and 65% RH) or ambient atmospheres. A third control was farmers stock peanuts bulk-stored in ambient atmospheric conditions. These peanuts were divided out of the total lot (approximately 2.5 tons) after initial drying to a moisture level of 7.9%. All treatments were stored in open-top pouch-lined fiberboard boxes.

All treatments and controls were replicated for each of three storage periods of 3, 6, and 12 months. At the end of each storage period, a replicated set of the samples was analyzed to determine the percentages of sound mature kernels (SMK), fall-through kernels (FTK), split kernels (SK), externally damaged kernels (EDK), bald kernels (BK), and moisture content (MC). The treatment numbers and grade-quality values at time of storage are given in table 2.

An evaluation of handling and shipping characteristics was made by shipping a palletized load of 24 packages and 24 individual packages approximately 1,600 miles round trip to determine the ability of the packages to protect the peanuts from handling damage and to maintain atmospheric integrity.

Stacking-strength tests were made on the packages when they were received at the laboratory of Container Corporation of America. Stacking-strength specifications for the box design required a four-high pallet stack with six layers per pallet. Tests were based on an equivalent column stack that was 24 boxes high, with box dimensions of 15⅛ by 7⁹⁄₁₆ by 17¾ inches for machine pallet handling efficiency.

In this investigation germination was included as an analysis factor, but peanut seed quality was very poor and a separate investigation was conducted. Good quality 'Florunner' seed peanuts were obtained from the Georgia State Seed Development Center in Plains, Ga. The seed were mixed and divided into samples weighing approximately 4 lb with the Federal-State shelled-stock divider. One-half of the samples were treated with a commercially available fungicide commonly used by seed shellers; the remaining samples were left untreated until after storage. The samples were placed in cotton-cloth bags and inserted in laminated plastic bags (nylon-EVA resin) containing approximately 20 lb of peanuts to determine the effects of three pairs of variables: (1) two atmospheres, vacuum at 26 inHg or initial vacuum to 26 inHg with nitrogen gas backflush to 10 inHg vacuum; (2) two fungicide treatments, peanut seed treated with fungicide before storage or seed treated after storage; and (3) two packaging conditions, treated and untreated seed stored individually in separate plastic bags or treated and untreated seed stored in the same plastic bag (table 3). The controls were treated and untreated

Table 3. — Experimental treatments for peanut germination tests

Treatment No.	Description			
	Packaging materials	Packaging condition[1]	Atmosphere[2]	Fungicide treatment
1	Burlap[3]	Separate	Ambient	After storage.
2	Burlap[3]	Separate	Ambient	Before storage.
3	Burlap[4]	Separate	Refrigerated	After storage.
4	Burlap[4]	Separate	Refrigerated	Before storage.
5	Nylon-EVA	Separate	Vacuum	After storage.
6	Nylon-EVA	Separate	Vacuum	Before storage.
7	Nylon-EVA	Separate	N_2BF	After storage.
8	Nylon-EVA	Separate	N_2BF	Before storage.
9	Nylon-EVA	Combination	Vacuum	After storage.
10	Nylon-EVA	Combination	Vacuum	Before storage.
11	Nylon-EVA	Combination	N_2BF	After storage.
12	Nylon-EVA	Combination	N_2BF	Before storage.

[1]Separate, treated and untreated seed stored individually in separate plastic bags. Combination, treated and untreated seed stored in the same plastic bag.
[2]N_2BF, nitrogen backflush.
[3]Control, treated and untreated seed in separate bags.
[4]Control, treated and untreated seed in separate bags stored at 37° F and 65% RH.

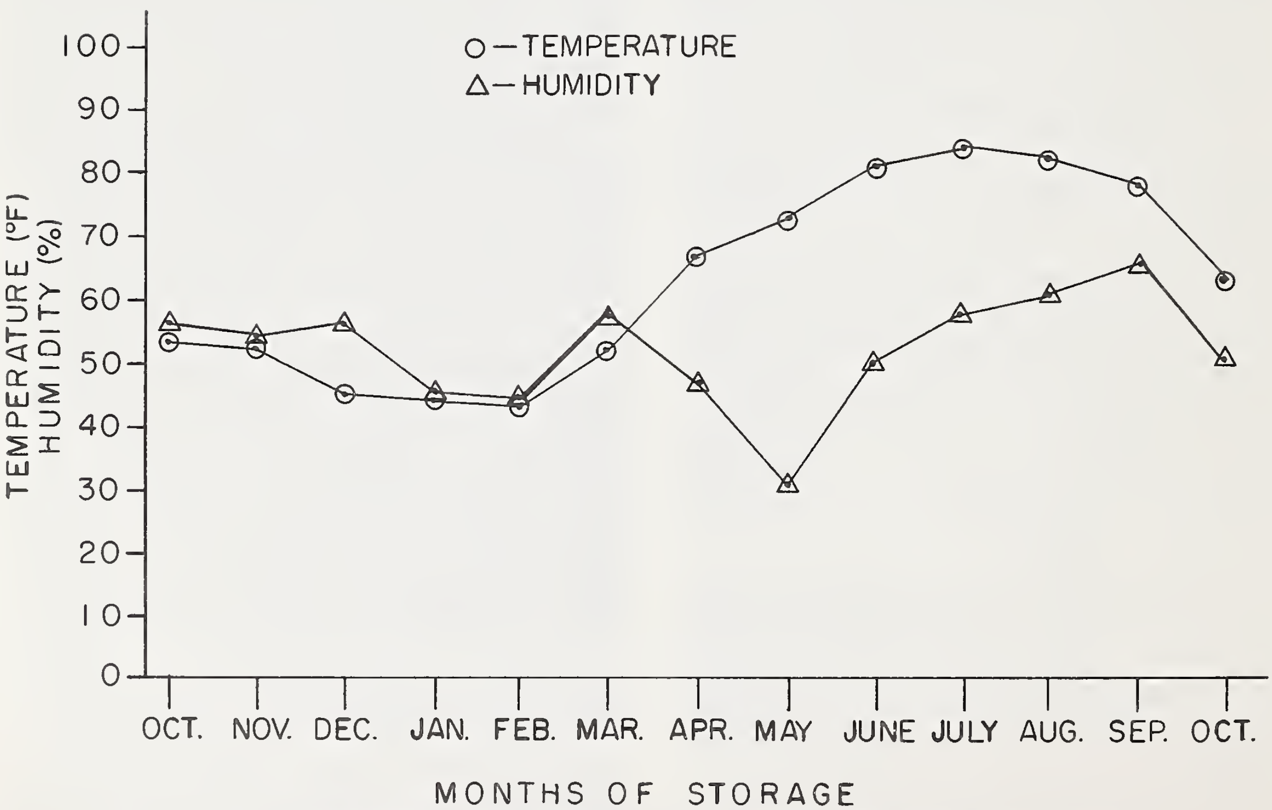

FIGURE 1. — Average storage temperature and humidity by month for the 12-month storage period.

Table 4. — Mean values (%) of grade-quality factors for peanuts after 3 months of storage[1]

[In order of decreasing outturn or moisture content]

Treatment No. and value[2]											
SMK		FTK		SK		BK		EDK		MC	
No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value[3]
2	98.9a	11	3.7a	11	3.2a	11	0.5a	11	1.7a	8	7.8a
9	98.9a	7	3.4a	3	.7b	3	.1b	5	0b	6	7.7a
6	98.7ab	3	3.2ab	7	.5bc	1	.1b	7	0b	4	7.7a
8	98.3ab	1	2.4bc	1	.4cd	5	0b	1	0b	2	7.7a
4	98.0abc	5	1.9cd	10	.4cd	7	0b	2	0b	9	7.6a
5	97.8bc	10	1.9cd	5	.3de	2	0b	3	0b	11	6.8b
10	97.7bc	4	1.8cde	9	.2e	4	0b	4	0b	5	6.5c
1	97.0cd	8	1.5de	4	.2e	6	0b	6	0b	10	6.5c
7	96.1d	6	1.2de	8	.2e	8	0b	8	0b	1	6.5c
3	96.1d	2	1.1de	6	.1e	9	0b	9	0b	7	6.4c
11	69.4e	9	.9de	2	.1e	10	0b	10	0b	3	6.2d

[1]See table 1 for treatment descriptions. SMK, sound mature kernels. FTK, fall-through kernels. SK, split kernels. BK, bald kernels. EDK, externally damaged kernels. MC, moisture content.
[2]Means in a column followed by different letters are significantly different at the 0.05 level.
[3]Values represent all peanut samples within a given treatment.

seed in separate burlap bags stored in refrigerated (37° F and 65% RH) and ambient atmospheres.

Three replications of each treatment and control were prepared for each of three storage periods. At the end of 3, 6, and 12 months of storage, a replicated set of samples was analyzed for percentage of germination.

RESULTS

Analysis of variance of quality factors by storage period indicated significant differences between treatments and controls (tables 4, 5, and 6). Interactions between atmospheres and peanut moisture content existed, but pouch materials had no apparent effect.

Figure 1 shows the average storage temperature and humidity by month for the 12-month storage period. The averages do not reflect temperature extremes, which ranged from a high of 96° F in July to a low of 27° F in December. Humidity extremes, which also are not reflected in figure 1, ranged from a high of 94% in December to a low of 24% in January.

Sound Mature Kernels

The nitrogen atmospheres maintained SMK content better than the vacuum atmospheres or the controls; the mean initial content for both experimental treatments was 97.8%. After 12 months of storage the mean SMK content was 97.9% and 97.1%, respectively, for the nitrogen and vacuum atmospheres. The SMK content of the refrigerated control was 95.8% after 12 months of storage, with much higher losses in the other controls. There were significant effects of moisture content on SMK for each storage period, but after 12 months of storage only the low-moisture peanuts (6.9%) showed a loss (1.0%). There were significant differences between the individual treatments and controls, but in comparable moisture treatments the nitrogen atmospheres had less SMK loss than did the vacuum atmospheres. The low-oxygen atmospheres were all superior to the control methods in maintaining SMK grade quality after 12 months of storage.

Fall-Through Kernels

The FTK contents of the control treatments in burlap bags (ambient and refrigerated) and of the nitrogen treatments with the higher (7.6%) moisture contents were not significantly different after 12 months of storage. The nitrogen atmospheres were better than the vacuum atmospheres in maintaining grade quality, and after 12 months of storage the mean FTK content was 1.9% and 2.8%, respectively, for the nitrogen and vacuum atmospheres. There were significant effects of peanut moisture content on FTK outturn during all stor-

Table 5. — Mean values (%) of grade-quality factors for peanuts after 6 months of storage[1]

[In order of decreasing outturn or moisture content]

Treatment No. and value[2]											
SMK		FTK		SK		BK		EDK		MC	
No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value[3]
2	98.5a	11	4.5a	11	3.6a	10	0.8a	10	3.6a	4	7.1a
8	98.4a	3	3.6b	3	.3b	11	.5b	11	3.4a	9	7.0ab
6	98.1ab	7	2.8bc	7	.3b	9	.3c	9	2.3b	8	7.0ab
4	98.0ab	1	2.2cd	6	.2b	3	.1cd	3	.1c	6	6.9bc
5	97.8ab	5	2.1cd	9	.2b	7	0d	1	0c	2	6.8c
1	97.7abc	4	1.9cde	4	.2b	1	0d	2	0c	7	6.7d
7	96.9abc	6	1.7de	1	.2b	2	0d	4	0c	5	6.5e
9	96.3bc	8	1.5de	5	.1b	4	0d	5	0c	3	6.4e
3	95.9c	10	1.5de	10	.1b	5	0d	6	0c	1	6.4e
10	93.9d	2	1.4de	2	.1b	6	0d	7	0c	11	6.1f
11	66.7e	9	.9e	8	.1b	8	0d	8	0c	10	6.0f

[1]See table 1 for treatment descriptions. SMK, sound mature kernels. FTK, fall-through kernels. SK, split kernels. BK, bald kernels. EDK, externally damaged kernels. MC, moisture content.

[2]Means in a column followed by different letters are significantly different at the 0.05 level.

[3]Values represent all peanut samples within a given treatment.

Table 6. — Mean values (%) of grade-quality factors for peanuts after 12 months of storage[1]

[In order of decreasing outturn or moisture content]

Treatment No. and value[2]											
SMK		FTK		SK		BK		EDK		MC	
No.	Value	No.	Value	No.	Value	No.	Value	No.	Value	No.	Value[3]
6	98.8a	11	4.5a	11	5.0a	10	1.0a	11	2.9a	9	8.2a
2	98.2ab	7	3.4b	10	.3b	11	.7b	9	2.7b	6	7.8ab
8	97.7bc	3	3.3bc	5	.3bc	9	3c	10	2.6b	8	7.8ab
4	97.6bc	5	2.5bcd	2	.2bc	1	0d	1	0c	2	7.7ab
1	97.4c	1	2.4cd	9	.2bc	1	0d	2	0c	4	7.4bc
5	97.2cd	8	2.3d	1	.2bc	3	0d	3	0c	7	7.0cd
3	96.6d	4	2.2d	4	.2bc	4	0d	4	0c	5	6.8d
7	96.5d	10	1.9de	6	.2bc	5	0d	5	0c	1	6.8d
9	95.8e	2	1.6de	3	.1bc	6	0d	6	0c	3	6.5d
10	94.2f	6	1.1e	7	.1bc	7	0d	7	0c	11	6.0e
11	65.4g	9	1.1e	8	[4].1c	8	0d	8	0c	10	5.6e

[1]See table 1 for treatment descriptions. SMK, sound mature kernels. FTK, fall-through kernels. SK, split kernels. BK, bald kernels. EDK, externally damaged kernels. MC, moisture content.

[2]Means in a column followed by different letters are significantly different at the 0.05 level.

[3]Values represent all peanut samples within a given treatment.

[4]Actual value was 0.05, which was significantly different from value for control treatment 10.

age periods. The FTK content of control treatment 11 was high, but it actually reflected less than a 1% increase during the 12 months of storage. Treatments 7 and 3 (vacuum with 6.9% moisture) had the largest decrease in grade quality as a result of FTK increase during storage.

Split Kernels

Although some significant differences were found between treatments and controls, they were too small to be of any practical significance. However, the results of control treatment 11 actually reflect the normal trend of higher SK outturn resulting from kernel moisture loss as storage time increased. Most of the SK increase in control treatment 11 was attributed to shelling and handling in preparation for grading. Control treatment 10 had a large moisture loss but was handled only during the grading process, which resulted in minimal SK outturn.

Bald Kernels

The BK contents of control treatments 10 and 11 were the only values having any practical significance. The data reflect the effects of moisture loss in these two controls resulting from ambient storage. Handling bald kernels often causes them to split, and the low value for control treatment 11 may reflect the greater amount of handling involved in preparing the peanuts for the grade analysis.

Externally Damaged Kernels

External damage consisted primarily of molded or discolored kernels but did include some worm-cut damage in control treatments 10 and 11. No insect penetration or activity was found in any of the packages in treatments 1 through 8 or in control treatment 9. All the controls had a substantial amount of external damage after 6 and 12 months of storage. Control treatment 11 actually increased external damage by only 0.5% during the 12 months of storage, but when compared with the results of the experimental treatments, this was a significant increase. The skins of the peanuts stored in nitrogen atmospheres were much brighter in appearance than those from the vacuum or control treatments.

Moisture Content of Kernels

At the time of packaging the mean moisture content of the peanuts in treatments 1 through 8 was 7.3%. After 12 months of storage, peanuts in the nitrogen and vacuum atmospheres had mean moisture contents of 7.2% and 7.1%, respectively. The mean moisture content of the control peanuts was 7.8% at the beginning of the tests and 6.6% after 12 months of storage. However, the data indicate that the mean moisture contents of both treatments and controls were lowest after 6 months of storage. This was not expected and a probable cause was found. Apparently, samples were removed from storage, graded, and then allowed to remain in open air for a prolonged period before moisture determinations were made. Rather than an apparent increase in moisture content from 6 to 12 months of storage, loss of moisture attributable to the delay in making moisture determinations at 6 months is reflected.

Shipping Tests

Nineteen of the twenty-four packages shipped individually were intact when returned to the National Peanut Research Laboratory. Three of the five ruptured packages had holes in both box and plastic liner, apparently caused by a sharp object. A fourth package was apparently struck by an object that tore the box but did not quite penetrate it; however, the plastic liner was ruptured at the impact point. All five of these packages were badly scuffed on the outside, apparently from receiving rough treatment. Examination of the plastic liner in the fifth package revealed a pinhole puncture. In this and other instances it was determined that the very sharp tips of some raw peanuts, when positioned perpendicular to the inner surface of the liner, create a very high stress point in the plastic when vacuums are used. Impact at this point often resulted in a pinhole rupture and eventual loss of package integrity. Subsequent tests indicated that this problem could be minimized by backflushing to a lower vacuum (8 to 10 inHg). However, materials that offer much better puncture resistance have become available since these tests were conducted.

All 24 boxes in the palletized shipment were intact when returned. Several boxes had scuff marks and signs of rough handling, but only one

was torn. Additional shipping tests are planned, using stronger pouch materials that are more resistant to puncture.

Stacking-Strength Tests

Bottom-box loads were calculated at 1,190 lb. Compression test loads of 4,790 lb, or approximately four times the calculated load, were obtained without box failure or significant damage to the peanuts. In other tests, box deformation exceeding three-fourths of an inch occurred without rupturing the plastic liner. Abrasion tests showed the box finish to be adequate in preventing rupture of the plastic liner from wear or scratching during handling.

Germination Tests

Results of the germination tests are shown in table 7. There was lack of consistency in percentage of germination for particular treatments as storage time progressed, but germination was generally better for the nitrogen treatments than for the vacuum treatments. There was some indication that treating seed with fungicide before storage adversely affected germination, but the results were just barely significant after 6 months of storage. The combined storage of treated and untreated seed did not affect germination. After 3 months of storage, all the control samples were lower in germination than were the experimental-treatment samples. However, results were not quite as consistent after 6 or 12 months, but the gradual decline in germination as storage time progressed is evident. After 12 months of storage, samples from all treatments and controls exceeded State germination standards, and three of the five that exceeded 80% germination had received nitrogen treatments.

COST FACTORS

The cost of a low-oxygen-atmosphere packaging and handling system will vary for many reasons. The extent of automation; type of equipment; package size; type, thickness, and strength of pouch-liner material; and barrier and sealing properties are a few of the factors involved in cost variation. If the use of the low-oxygen-atmosphere methods and systems permits entry into new market areas or provides significant improvement and advantages over existing methods, cost may be a secondary consideration. If, however, they are to be used as an alternative to existing methods and practices, the economics involved are a primary concern. Generally, costs will decrease as package quantities increase, i.e., it costs less to package in 100-lb quantities than in 25-lb quantities.

Another important cost consideration of the low-

Table 7. — Mean values (%) for germination of peanuts by storage period[1]

[In order of decreasing germination]

Treatment No. and value at —							
Time of storage		3 months		6 months		12 months	
No.	Value	No.	Value	No.	Value	No.	Value
2	92.5a	9	91.0a	7	86.7a	9	85.3a
4	92.5a	12	90.1a	4	85.0ab	12	85.3a
6	92.5a	6	89.8a	9	84.5abc	2	84.0a
8	92.5a	8	89.2a	11	84.3abc	11	82.7ab
10	92.5a	7	89.0a	5	83.2abc	7	81.0abc
12	92.5a	10	88.8a	2	82.8abc	5	79.3abcd
1	90.3a	5	88.7ab	1	82.5abc	10	77.3bcd
3	90.3a	11	88.5ab	3	82.0abc	1	76.5bcd
5	90.3a	3	86.3bc	8	82.0abc	4	76.5bcd
7	90.3a	1	84.5cd	6	81.0bc	8	76.3bcd
9	90.3a	4	82.8d	12	79.7c	3	75.5cd
11	90.3a	2	80.3e	10	79.3c	6	74.0d

[1]See table 3 for treatment descriptions. Means in a column followed by different letters are significantly different at the 0.05 level.

oxygen system is the extended quality preservation of peanuts and many other products without need of cold storage. Based on current refrigerated-storage rates, it costs approximately $15 to $18 per ton to store peanuts for 3 months. In most instances this will offset any cost differences between the low-oxygen and other packaging and handling methods. However, there are other advantages of the low-oxygen system to consider, such as product sanitation; protection from dirt, mold, or insect contamination; handling efficiency due to system automation; product moisture content retention; protection from outside moisture sources; and possible elimination of some handling and transportation costs not included in the cold-storage charges.

Because of the many cost variables and differences in importance of the various advantages to users, the economics of a low-oxygen system are best determined for each application. In most applications the packaging cost will probably range from 1.25 to 2 cents per pound. We suggest that interested users contact the manufacturers for additional information on prices and equipment.

CONCLUSIONS

Using recent developments in materials and equipment, this study shows the vast potential for low-oxygen atmospheres as a means of preserving the quality of peanuts and many other food products for extended periods. Containers made from materials much lower in cost than conventionally used metal or glass have proven reliable in maintaining atmospheric integrity for prolonged periods. The atmospheres can be easily applied to bulk quantities up to 2 cubic feet in volume, with the possibility of developing the system and methods for much larger bulk volumes.

In addition to advantages such as quality maintenance without cold storage, sanitation, insect protection, etc. (which have been cited in other research), the atmospheres were effective in maintaining peanut grade quality. The moisture-retention capability may be of particular significance because of the potential effect on milling yields. The potential appears to be even greater for the seed sheller, because milling yields are extremely important where a premium-priced product is involved.

One atmosphere was not consistently better than another in maintaining the germination and grade-quality factors. Other atmospheres or combinations of atmospheres presently being investigated may be better by showing more consistent results or perhaps by further enhancing germination or food-quality factors.

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